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Extraction of urban buildings using color image processing and morphological operations

Mete Durlu [a] *, Baskent University Department of Computer Engineering, Baglıca Kampjusu, Dumlupınar Blv. 20. Km, 06810, Turkey. 21593840@mail.baskent.edu.tr
Ozan Eski [b], Tobb University Of Economics And Technology Department of Economics, Baglıca Kampusu, Dumlupınar Blv. 20. Km, 06810, Turkey
Emre Sumer [c], Baskent University Department of Computer Engineering, Baglıca Kampusu, Dumlupınar Blv. 20. Km, 06810, Turkey. esumer@baskent.edu.tr

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Abstract
In many geospatial applications, automated detection of buildings has become a key concern in recent years. Determination of building locations provides great benefits for numerous geospatial applications such as urban planning, disaster management, infrastructure planning, environmental monitoring. The study aims to present a practical technique for extracting the buildings from high-resolution satellite images using color image segmentation and binary morphological image processing. The proposed method is implemented on satellite images of 4 different selected study areas of the city of Batikent, Ankara. According to experiments conducted on the study areas, overall accuracy, sensitivity, and F1 values were computed to be on average, respectively. After applying morphological operations, the same metrics are calculated . The results show that the determination of urban buildings can be done more successfully with the suitable combination of morphological operations using rectangular structuring element.

Keywords: Building Extraction; Colour Image Processing;Colour space conversion; Image Morphology; Remote Sensing

* ADDRESS FOR CORRESPONDENCE: **Mete Durlu***, Baskent University Department of Computer Engineering, Turkey.
Email: 21593840@mail.baskent.edu.tr

1. Introduction

Since urban areas have been populated by the largest part of the world population, geographical analysis methods such as urban planning, monitoring urban change and growth, civil protection, and environmental impact studies are required for solving many management issues. New constructions such as buildings, roads, and other man-made objects change the shape of urban areas, land cover and land use rapidly. Monitoring these changes is a critical task, and Geographic Information System (GIS) applications lack the timely land use information. Consequently, the guides should be routinely refreshed with the changes. To do that, for a long time, the extraction of geographic highlights has been performed physically by human administrators. However, this is a very time-consuming operation and requires qualified people. For that reason, geospatial applications inherited the solution of unsupervised object extraction on high-resolution images.

Improvements in satellite image quality and the trend towards computer vision caused the development of new image processing methods for object extraction. There are many applications to be able to efficiently extract individual objects from a scene for spatial analysis and object retrievals from large-scale image databases. Primary regions of interest for these applications consist of buildings, streets, highways, and urban territories in general.

Detection of buildings and their corresponding footprints is a major research area in remote sensing. This topic yields some of the most essential GIS data components. In many applications of building detection, spaceborne and airborne remote sensing technologies are widely used [1]. Determination of building locations, as a research problem, is extremely useful in city planning and city modelling. It also provides great benefits for numerous geospatial applications such as disaster management, infrastructure planning, environmental monitoring.

In building extraction, various sophisticated techniques such active as contours, mask R-CNN and image fusion have been employed while working with multi-spectral imagery [2,3,4]. For each pixel in each spectral channel, the set of intensity values enables the construction of spectral input vectors. While the general approach is using these vectors for conventional classifiers, relying solely on texture, proximity or shape can also be successful for feature extraction. Therefore, to extract urban objects with high accuracy rates, images have undergone segmentation operation [5][6][7]. After this process, morphological structures have been carried out and urban areas in the image are detected more successfully than previous detection processes.

1.1. Purpose of study

In this study, it is aimed to detect building regions from high-resolution satellite images using color image processing and image morphology. In contrast to previous efforts, which employ sophisticated classification and segmentation approaches, in this study, a high percentage of building detection was obtained by using extremely basic image processing functions. Furthermore, the present study can be said to be cost-effective since LIDAR or any additional ground-level data was not employed. Instead, all the processes were carried out on single satellite imagery.

2. Materials and Methods

2.1.Data collection

Our data set consists of satellite images of 4 different selected regions from the city of Ankara. The images were acquired on August 4, 2002 in "Geo" data format. To obtain satisfactory results with color-based segmentation, high resolution and multispectral satellite imagery are used. Since coloured images have lower spatial resolution compared to panchromatic images, enhancement of RGB imagery with the pan-sharpening operation was utilized. Panchromatic images with 1-m resolution and RGB images with 4-m resolution belonging to the same regions were acquired from the IKONOS satellite. Figure 1 illustrates the pan-sharpened images in false color composite belonging to our study area. To measure the accuracy of our approach, a binary ground-truth data for each region were prepared manually.

Figure 1. Pan-sharpened Images of the Study Area

For our dataset, it is possible to segment regions by defining specific color thresholds for each spectral channel present. This method, although being relatively simple, is a common method for years and can be seen yielding prolific results on various other works. Furthermore, in the current study, partial improvements on our initial segmentation results have been accomplished by applying morphological operations. Although morphological operations are quite basic and widely used, these operations may have degrading impacts on images since they can alter the shapes of the objects significantly. By applying different kernels and different kernel sizes, the results can be manipulated as desired. In our work, we used morphological operations to enhance segmentation results and improve performance metrics such as the F1 score. In the following sections, the general workflow of our methodology is discussed in detail.

2.2. Research procedure

In our process workflow (Figure 2), first, we take the satellite image and convert it to a different color space. Since RGB color space uses all its channels for color representation, it is harder to use for segmentation. Experiments were conducted with various color-spaces and LAB color-space was found to be the most useful [8][9][10]. After adjusting the color-space, different threshold values are determined for each channel separately. Thresholding operation masks out the desired regions for each channel then a logical-and operation is performed to determine the regions to be segmented. If segmentation returns a few regions, previous steps are repeated with new threshold values. This process continues until a satisfactory number of regions is obtained. Lastly, a patch area filter is applied and morphological operations such as closing, or dilation are performed to improve the morphology of the retrieved building regions.

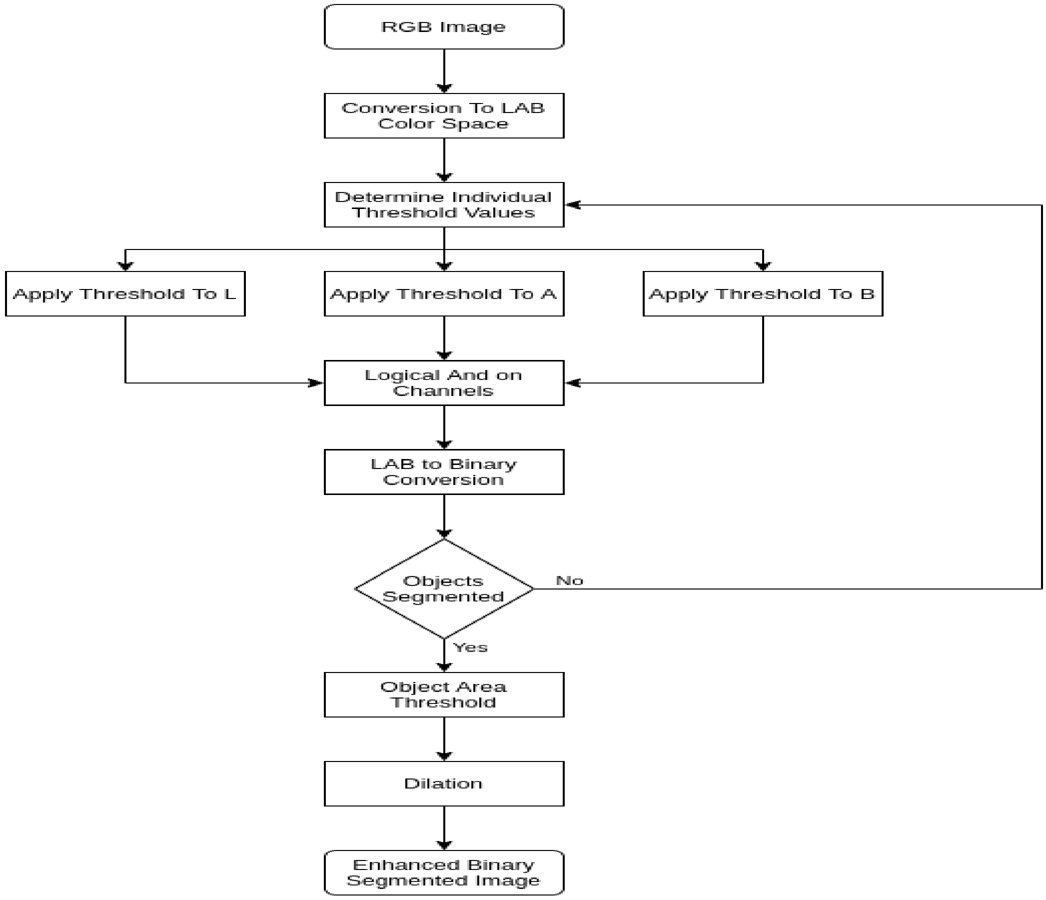

Figure 2. Process Workflow

2.2.1. Color-Space Conversion

Since we are segmenting regions by their colors, we need the best color space to represent the building patches. Throughout this work, several color-spaces including RGB were tested for segmentation. We have observed the most success with HSV [11] and LAB formats. HSV format channels contain Hue, Saturation, and Value (brightness or lightness). The hue channel represents the color values like how humans perceive colors and since HSV is a continuous model it is easier to discriminate colors from each other. Another format that we examined is LAB color space. Here the channels keep values for Lightness, Red/Green(A), and Blue/Yellow(B). Although it is quite similar to the HSV color-space we achieved better segmentation accuracy using the LAB color space.

2.2.2. Threshold Value Determination

After converting the image to LAB color-space, a good representation of the desired color is required. In LAB color space we need all channel values for segmentation. To determine upper and lower color limits for segmentation, we take pixel values from 50 random sample points on target color or target ROI. Minimum values within collected samples define the lower bounds and maximum values define the upper bounds. The values are determined for each channel separately.

2.2.3. Applying Thresholds for All Channels

Once the upper and lower bound values are determined, we filter out irrelevant regions on each channel. If a pixel value is outside of the boundaries, then it is set to zero, else the value stays like the original.

2.2.4. Combining Building Regions with Logical-And Operation

Applying thresholds on channels yields us a map of regions on each channel. Our problem is to find the common regions in all three thresholded channels. To produce the combined result which is the binary segmentation map, we apply a logical-and operation among all three channels. This is the equivalent of finding all the regions that match the threshold boundaries for the LAB image.

2.2.5. Segmentation Evaluation

The thresholded mask contains the merged data from all three channels. When we compared this mask with the ground-truth of segmentation, we can measure accuracy, sensitivity, specificity, precision, NPV (Negative Predictive Value), and F1 score (Equations 1 - 6). Pixel-wise comparison gives us the amounts of True-Positive (TP), True-Negative (TN), False-Positive (FP), and False-Negative (FN) pixels.

Sensitivity: $$\frac{TP}{(TP+FN)} \quad (1)$$

Specificity: $$\frac{TN}{(TN+FP)} \quad (2)$$

Precision: $$\frac{TP}{(TP+FP)} \quad (3)$$

Accuracy: $$\frac{TP+TN}{(TP+TN+FP+FN)} \quad (4)$$

NPV: $$\frac{TN}{(TN+FN)} \quad (5)$$

F1: $$\frac{2*TP}{2*TP+FP+FN} \quad (6)$$

2.2.6. Area Thresholding

After verifying the binary mask produced by segmentation, we need to subtract the small errors and noise left by filtering regions. To do that we determined an area threshold by making observations on different images and found out that regions smaller than 70 pixels are considered as non-building regions. The effect of area thresholding is illustrated in Figures 3 and 4.

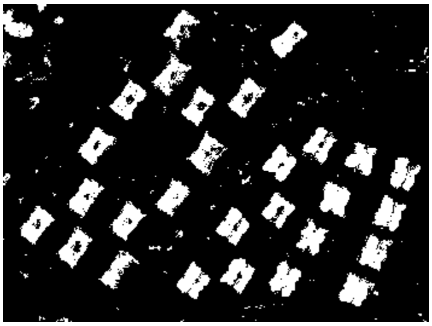

Figure 3. Before Area Filtering

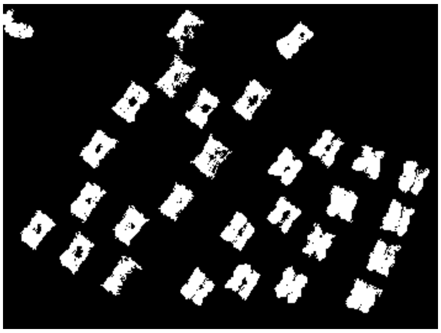

Figure 4. After Area Filtering

2.2.7. Applying Morphological Dilation

After the noise elimination, the morphological enhancement step is employed. In this step, we experimented with all different combinations of morphological operations such as "opening after dilation", "erosion after dilation", "dilation alone" and "closing alone". Due to the nature of morphological operations, kernel-size and kernel-shape are the key parameters for adjustment. It was experimented on kernels with various shapes and sizes. Among these combinations, dilation with 3-by-3 rectangle-shaped kernels generally performed better. For all study areas at least a 2% performance increase has been measured due to morphological post-processing.

3. Results and Discussions

To implement the proposed approach, a script was developed using the MATLAB programming tool, which provides a set of powerful image processing modules and a user-friendly programming environment [12].

Next, the parameters of the algorithm were initialized. The threshold values of LAB color space were set differently for each image and regions below 70 pixels were removed. In Figures 5-8, the resulting segmented building regions before and after the image morphological, are demonstrated.

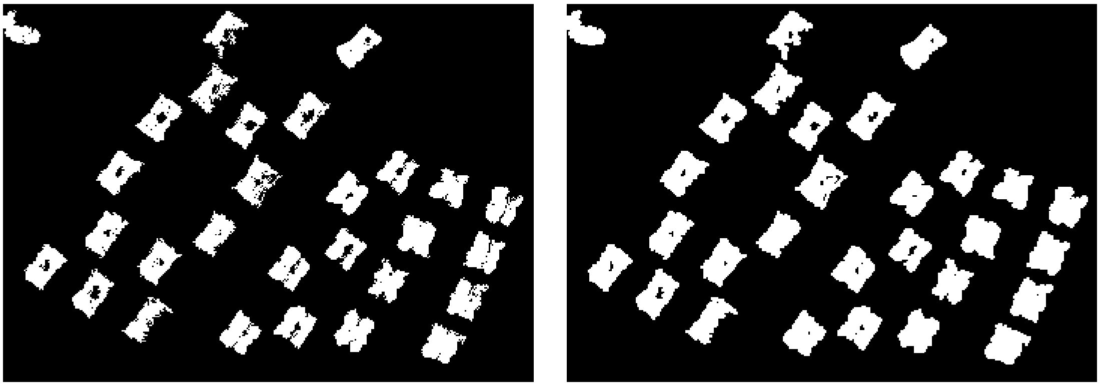

Figure 5. Segmented Building Regions Before (Left) and After (Right) Image Morphology for Scene-1

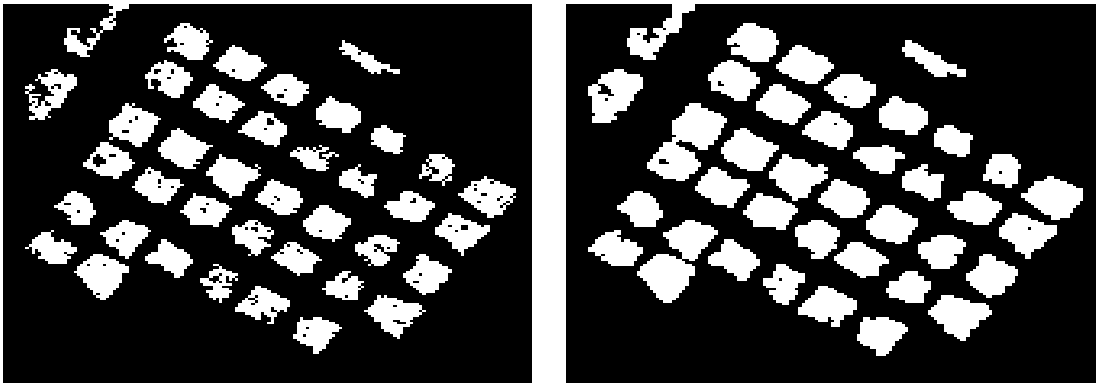

Figure 6. Segmented Building Regions Before (Left) and After (Right) Image Morphology for Scene-2

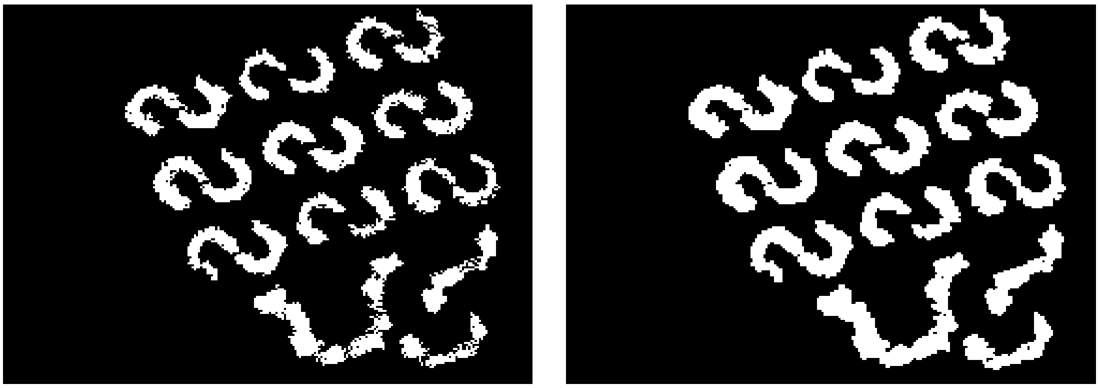

Figure 7. Segmented Building Regions Before (Left) and After (Right) Image Morphology for Scene-

3

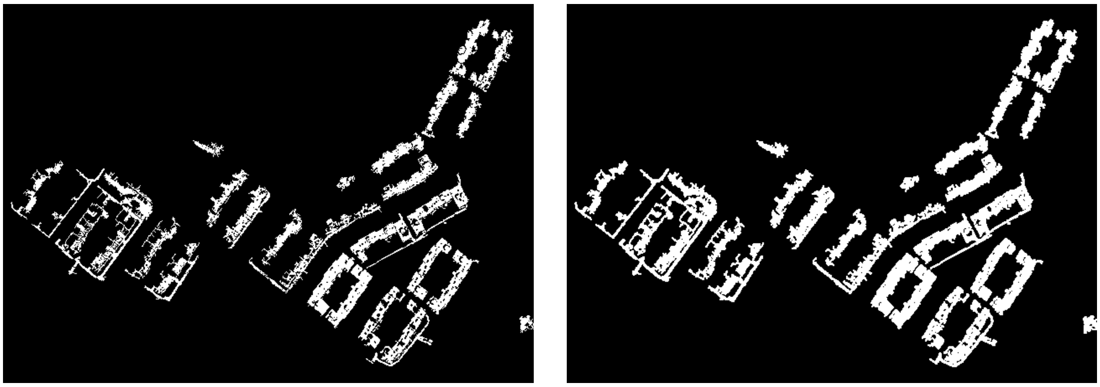

Figure 8. Segmented Building Regions Before (Left) and After (Right) Image Morphology for Scene-4

For Scene-1, the performance metrics: Accuracy, Sensitivity, and F1 score were computed as 94.8%, 96.7% and 97%, respectively. After applying the morphological operations those statistics were changed as 95.3%, 98.1% and 97.2% respectively. The same metrics for Scene-2, were found to be 88.2%, 87% and 92.3%. After applying the morphological operations those statistics were improved as 88.8%, 90.3% and 92.3%, respectively.

For Scene-3, the accuracies were computed to be 89.8% (without applying morphological operations) and 92.6% (after applying morphological operations). Similarly, Sensitivity scores were found to be 89.3% (without applying morphological operations) and 93% (after applying morphological operations). Finally, F1 scores were calculated as 93.8% (without applying morphological operations) and 95.4% (after applying morphological operations).

For the last scene (Scene-4), Accuracy, Sensitivity, and F1 score were computed as 90.5%, 91.8% and 94.7% respectively. After applying the morphological operations those statistics were changed as 90.5%, 93.4% and 94.6%, respectively.

The above-given values of the parameters were chosen by experience and have been found to work well over many different experiments. The results showed that applying morphological image processing operations is extremely useful for each scene. The best results were obtained in Scene-1 since the region contains well separated buildings and the geometry of the buildings are simple. On the other hand, the worst results were obtained in Scene-2. This is due to the fact that this region contains closely located small buildings. It is also observed that the buildings having complex geometries in Scene-3 and Scene-4 were extracted successfully.

4. Conclusions

Automated detection of buildings has become a key concern in many geospatial applications in recent years. Urban planning, disaster management, infrastructure planning, environmental monitoring, and many more geospatial applications can benefit greatly from the determination of building locations.

The study presents a practical technique for extracting the buildings from high-resolution satellite images using color image segmentation and binary morphological image processing. Our proposed technique for extracting the buildings from high-resolution satellite images promises a low-cost, high-performance, and easy-to-apply approach. The current study can be said to be cost-effective since LIDAR or any ground-level data was not used. Instead, only single satellite imagery was employed. On the other hand, the study contains a considerably basic approach and there are many aspects to be generalized in the future.

As a limitation, since our approach is based solely on color segmentation, our approach would not work properly in a situation where the buildings and the background are made up of similar colors. Further, the initial parameters need to be generalized by automated approaches. Such kind of issues can be addressed in further studies.

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